X Y - Si_3N_4-membrane

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Spin deposition of polymers over holes and cavities

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Abstract

In this paper we report how polymers can be spin deposited on a perforated membrane in order to seal the holes in it. This is a low-temperature and potentially low-cost process that is compatible with VLSI processing techniques. The method has been demonstrated on a capacitive pressure sensor. This shows that it has the potential of being widely used in future microstructures.

Keywords: Microstructures; Polymers; Spin deposition

1. Introduction

Cavities play an important role in the fabrication of microstructures such as pressure sensors [1], accelerometers [2] and fluidic systems [3]. In bulk micromachining anisotropic etching of silicon in combination with anodic or fusion bonding [4] is used to form closed cavities [5]. Surface micromachining was introduced as a means of fabricating structures on the surface of a wafer using VLSI-compatible techniques [6,7]. Surface micromachining often relies on a selectivity in etch rate for various materials. This makes it possible to use sacrificial layers to form cavities and membranes. The etch selectivity, however, puts constraints on the design and the materials used to form such cavities. Closing the cavities often used thermal oxidation of silicon, deposition of an insulator such as low-pressure chemical vapour deposition (LPCVD) oxide or deposition of a metal by means of sputtering. Processes requiring elevated temperature or vacuum are disadvantageous, since they may damage sensitive integrated electronics or fragile microstructures. This paper introduced a novel method of forming closed cavities using spin deposition of polymers.

2. Experimental

Spin deposition is the most widely used technique for applying polymers for VLSI applications. The coating procedure involves three stages; dispensing of the liquid polymer; accelerating to the final spin speed; and spinning at a constant speed. At the dispensing stage, a spreading cycle at 200 r.p.m. for 2 s is used to produce a uniform liquid layer across the wafer. During an acceleration of 50 000 r.p.m. s^{-1} a wave of polymer is created and then moves to the wafer edge. Centrifugal forces drive the surplus polymer off the wafer leaving a uniform wet film. Spinning the wafers at constant speed for about 30 s dries the polymer. The final polymer film thickness is a function of the viscosity and spin speed.

If the wafer surface contains deep, narrow cavities the polymer can be spin-deposited into a film on the surface, not entering the cavities. The polymer forms a membrane at the opening of the hole, in parallel with the wafer surface (see Fig. 1). This is due to the surface tension of the liquid during the spreading phase. High viscosity and low spin speed are favorable for this process; the spreading cycle is important and the

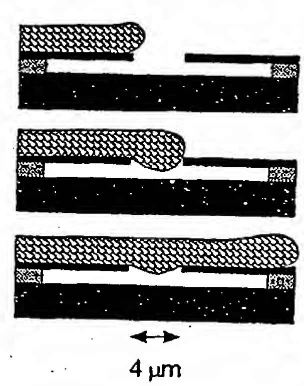

Fig. 1. Surface tension prevents the polymer from entering the cavity during spin deposition.

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the result. This behavior has been observed with Shipley Microposit 1813 photoresist, Ciba–Geigy HTR 3-50 and HTR 3-100 polyimide and Corning Q1-4939 silicone elastomer. This method of sealing cavities with polymers has been used in combination with a sacrificial oxide etch in order to form laterally extended cavities. The feasibility of this process is demonstrated on a capacitive pressure sensor.

The capacitive pressure sensor consists of two electrodes; the silicon substrate and the final aluminum metal. The cavity is etched in a sacrificial oxide layer. The flexible membrane is a sandwich structure of a nitride etch mask perforated with holes, the covering polyimide membrane and the aluminum electrode (see Fig. 2). The sensor was designed with square membranes with side lengths ranging from 54 to 186 μm. Several cavities were electrically connected in parallel on an area of 3 mm$\times$4 mm giving a total capacitance of 80 pF. The most sensitive sensor has a working range of 0–2 bar.

N-type silicon wafers with a diameter of 100 mm were doped with phosphorus on both sides from $POCl_3$ giving a sheet resistivity of 3 $\Omega/\square$. Low-temperature oxide (LTO) (4% PSG) was deposited with a thickness of 1.2 μm in order to form the sacrificial layer. A 100 nm thick film of LPCVD nitride was deposited to form the etch mask. The nitride layer was etched in a photolithographically defined pattern consisting of a large number of 4 μm diameter holes with a typical pitch of 20 μm. The holes may be designed to cover any form, in this case squares. The sacrificial oxide was etched through the holes in the surface of the silicon nitride membranes. The large density of holes minimizes the time required to remove the sacrificial layer beneath the membrane connecting each microcavity to one common cavity of large area and small height (see Fig. 3). Typical etch times were 55 min at an LTO etch rate of 0.26 μm min^{-1} in buffered HF. A Ciba–Geigy HTR 3-100 polyimide film was subsequently spun 2.5 μm thick (at 8000 r.p.m.) on top of the perforated membrane. The surface tension prevents the polymer from penetrating the holes in the membranes, thus closing the cavity. After curing the polyimide at 250 °C, a 0.5 μm sputtered aluminum layer was patterned

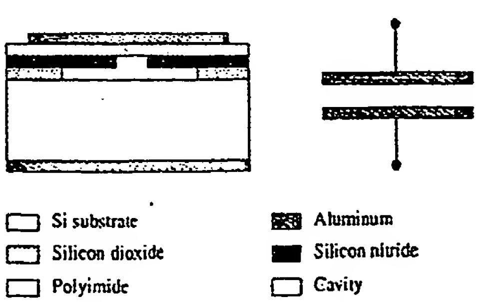

Fig. 2. The membrane of the capacitive pressure sensor consists of silicon nitride, polyimide and aluminum.

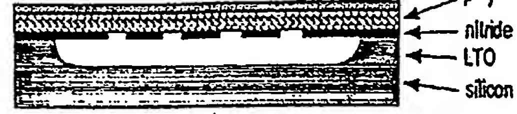

Fig. 3. Several microcavities are combined into one common cavity, thus reducing etch time and the need for etch selectivity.

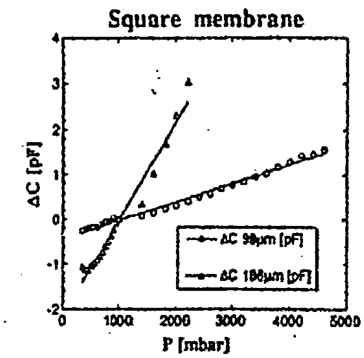

Fig. 4. Measured change in capacitance as a function of applied pressure. Plots from two different measurements (high and low pressure) are connected at $P = 1000$ mbar.

into electrodes and etched. Finally a contact was etched to the backside of the wafer before aluminum was sputtered to form the bottom electrode.

3. Results and discussion

The pressure sensors were characterized both below and above atmospheric pressure in two different measurement setups. The results have been plotted together in Fig. 4. Measurements on fabricated sensors result in a sensitivity of 31 ppm mbar^{-1}, a resolution of 0.04 mbar (on the condition that a change of 0.1 fF capacitance is detectable) and a linearity better than 1.5% of full range. Test wafers were covered with polyimide and cured in the same manner as for the pressure sensors. The measured bow allowed for calculations of the stress in the cured polyimide. The stress was 0.1×10^9 N m^{-2} (an order of magnitude higher than for the silicon nitride) and thus governs the mechanical behaviour of the sandwich membrane. The stress in the polyimide lowers the sensitivity but increases the linearity for the pressure sensor. The characterization of the sensors was carried out under conditions where the temperature was kept constant, since the sensor is filled with gas that otherwise would expand. The temperature dependence was 10.5 mbar °C^{-1} as measured on a hot chuck cycled from 20 to 100 °C.

There are many possible ways to make a sensor based on this concept. In order to decrease the electrode spacing, a conductive electrode material could have been used for the etch mask before applying the sealing polymer. We have chosen silicon nitride for the sacrificial etch mask because it is transparent and thus allows

inspection of the etched cavities. The sacrificial layer etch may be used in any combination of materials if there exists an etch with reasonably high selectivity between the masking material and the sacrificial layer. All sorts of polymeric materials can be used, i.e., photoresist, polyimide and silicone elastomers were investigated in this study and found to have the same covering behavior.

Integration of a sensor in a VLSI process is a difficult task and the presented method can hopefully work as an alternative to existing methods.

4. Conclusions

A method of forming closed cavities by spin deposition has successfully been demonstrated on a capacitive pressure sensor. These cavities can easily be implemented on wafers with processed integrated circuits, e.g., it should be well suited for sensor fabrication on foundry-processed wafers or chips from a multi-project wafer run. It is also possible to use the technique to form buried capillaries, valve membranes, thermally isolated structures, etc.

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